US LHC Accelerator Research Program

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Fermilab Accelerator Advisory Committee
20 November 2003

Goals of the US LARP

Advance High Energy Physics

- Help bring the LHC on and up to design performance quickly.
- Improve LHC performance by advances in understanding and instrumentation.
- Use LHC as a tool to gain deeper knowledge of accelerator science and technology.
- Extend LHC as a frontier HEP instrument with a timely luminosity upgrade.

Advance U.S. Accelerator Science and Technology

- Keep skills sharp by helping commission the LHC.
- Conduct forefront AP research and development.
- Advance U.S. capabilities to improve the performance of our own machines.
- Prepare U.S. scientists to design the next generation hadron collider.
- Develop technologies necessary for the next generation of hadron colliders.

Advance International Cooperation in the High Energy Accelerators

Overview of the Technical Program

- Help commission the hardware delivered by the US LHC Accelerator Project and later by the LARP
- Help commission the LHC with initial beam.
- Develop and build new instruments that will improve the operation of the LHC and help us perform accelerator physics experiments.
- Use the LHC to perform experiments and test calculations and theories of fundamental accelerator science.
- Perform accelerator physics studies and advanced magnet R&D that will result in the IR designs and prototype IR magnets for a timely LHC luminosity upgrade.

Schedule – Commissioning and Instrumentation

The LARP schedule is driven by the LHC schedule:

- August 2004 – Installation of US-provided equipment begins.
- April 2005 – Hardware commissioning of 1st US-provided IR.
- April 2006 – Sector test with beam.
- April 2007 – First beam in LHC.
- July 2007 – First LHC collisions.
- 2007 - 2010 – LHC luminosity rises towards design value.

⇒Hardware commissioning activity peaks 2005-2007.

⇒Beam commissioning peaks 2007-2009.

Preparations must start in 2004 to allow us to be fully integrated with CERN so we can have maximum impact.

⇒Beam instrumentation R&D must start *now* so that the instruments we develop contribute to the efficient commissioning the LHC.

Schedule – Accelerator Physics and Upgrades

- 2007 - 2010 – LHC luminosity rises towards design value.
- 2011 - … – LHC runs at asymptotic performance parameters.

⇒LHC will be the forefront vehicle for high energy hadron accelerator physics as soon as it is operational.

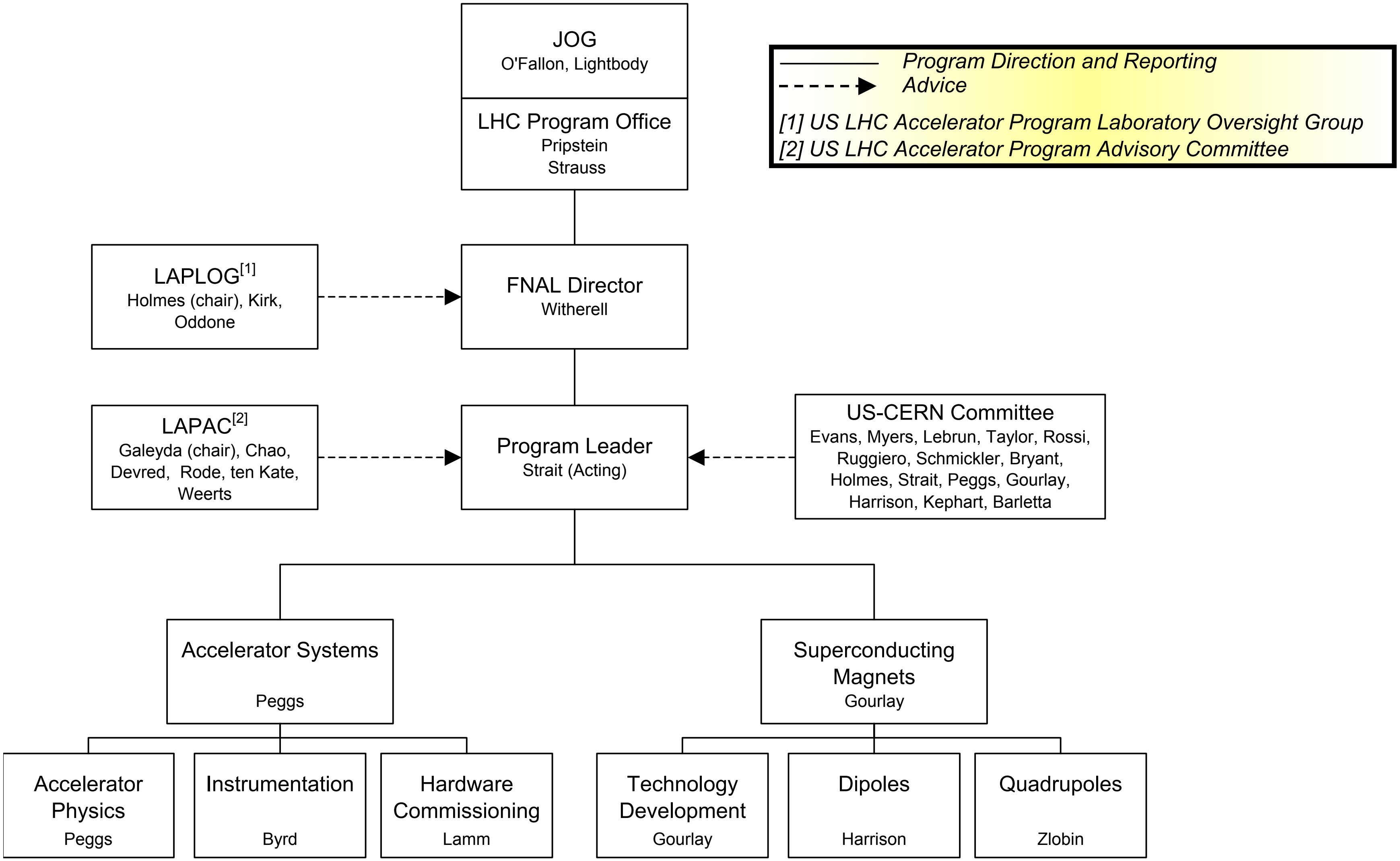
Fundamental accelerator physics research based on the LHC must start well before this so that we are ready to exploit this opportunity.

⇒Significant upgrades to the LHC and its experiments will be required by the middle of the next decade to extend its physics reach and keep its physics program productive.

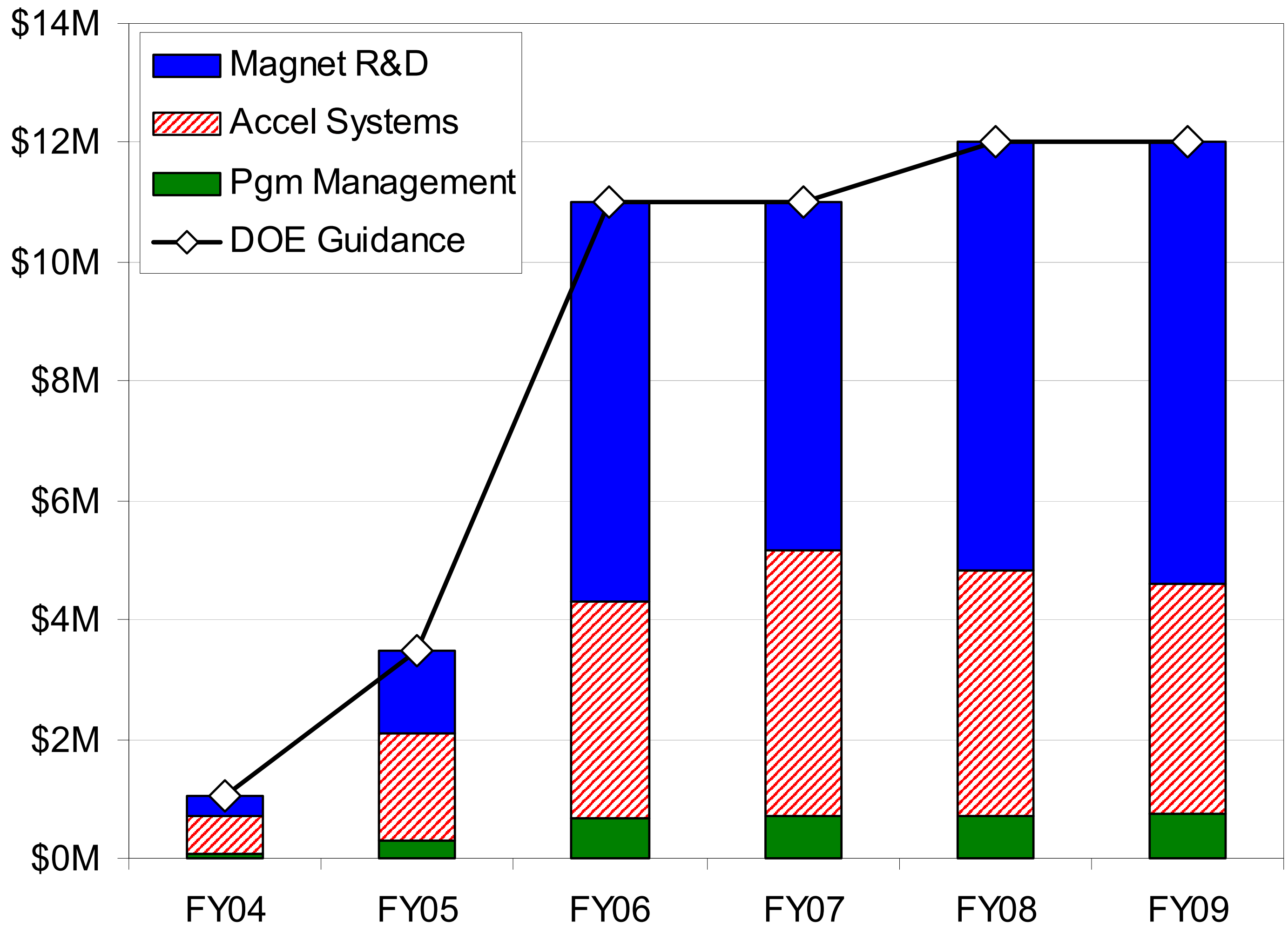
Extensive R&D will be required to develop the accelerator physics understanding and the beyond-the-state-of-the-art technologies required to push the LHC beyond its already demanding parameters.

… This R&D must start *now* to ensure we are ready for the upgrades.

Organization and Management



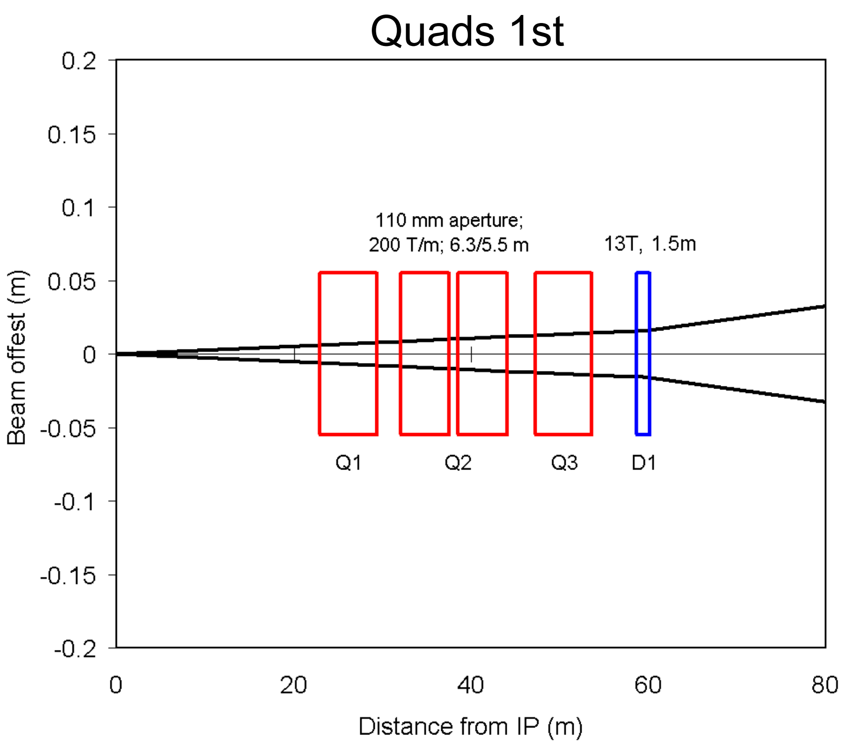
Budget

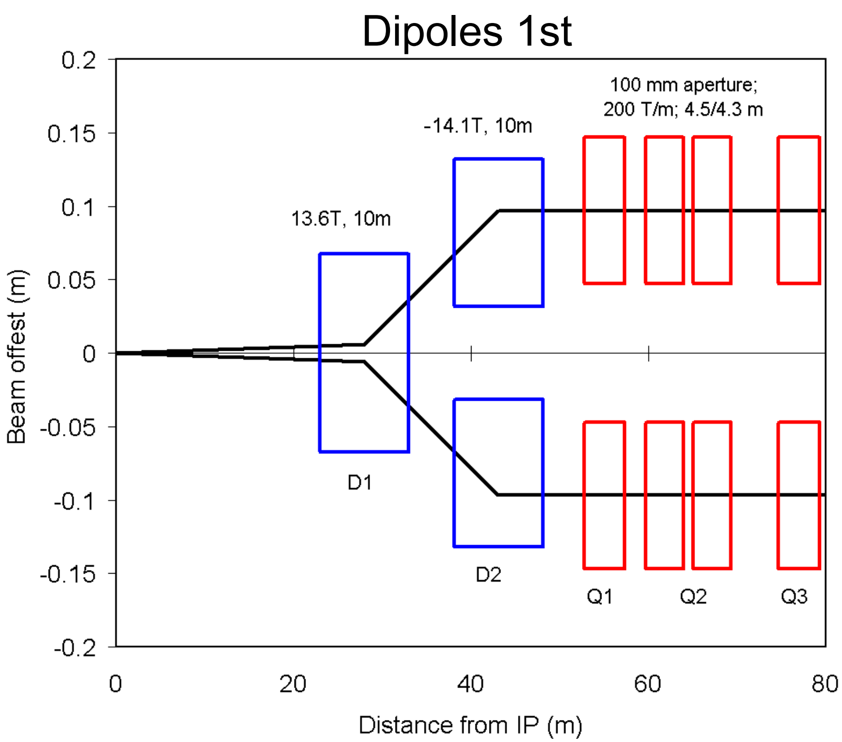

$14M
$12M
$10M
$8M
$6M
$4M
$2M
$0M
Magnet R&D
Accel Systems
Pgm Management
DOE Guidance
FY04
FY05
FY06
FY07
FY08
FY09

FY2004 Budget

	US LARP FY2004 Budget						
	FTE	M&S (k$)	Total (k$)	BNL	FNAL	LBNL	SLAC
Totals	5.7	141	1250	330	329	471	120
"Beams Div"				170	141	296	
"Magnet Div"				160	188	175	
Accelerator Systems	3.7	107	837	203	185	329	120
Instrumentation	1.5	82	380	69	69	242	0
Tune feedback	0.5	41	138	69	69		
Luminometer	0.6	41	162			162	
LDM	0.4		*80*			*80*	
Accel Phys	1.5	15	181	55	72	54	
Beam Comm	0.2	2	46	46			
Collimation			*120*				*120*
Hdw Comm	0.5	8	110	33	44	33	
Magnet R&D	1.6	29	325	105	100	120	
Technology Dev	1.2	29	245	65	60	120	
Quad design	0.2		40		40		
Dipole design	0.2		40	40			
Program Management	0.4	5	88	22	44	22	

New IRs:
"Straightforward" Designs

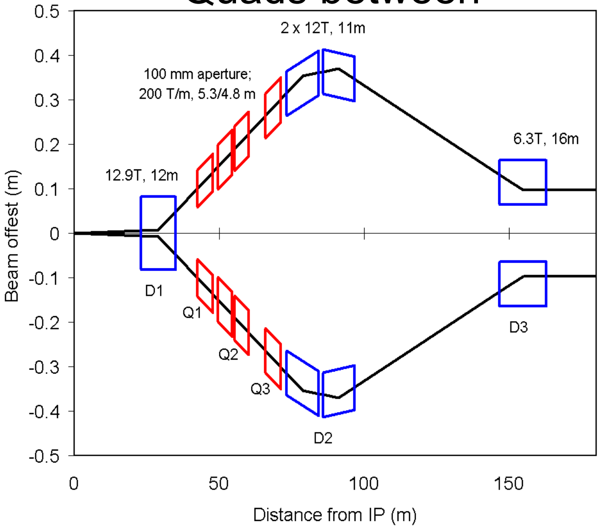




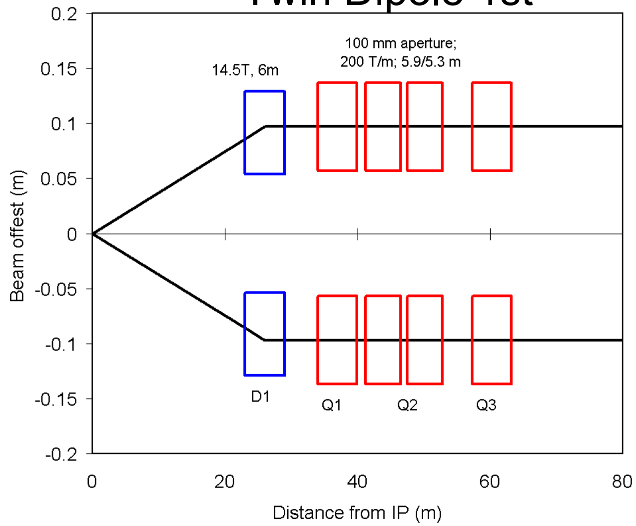
J. Strait, et al., Towards a New LHC Interaction Region Design for a Luminosity Upgade, PAC 2003.

New IRs: Alternate Designs

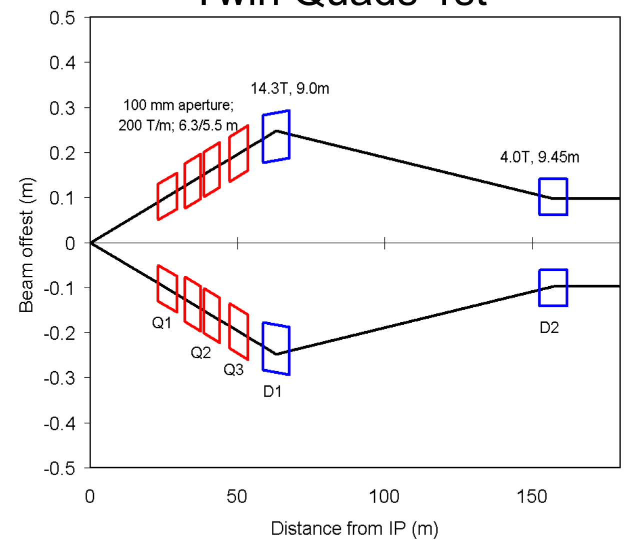
Quads between



Twin Dipole 1st



Twin Quads 1st



Preliminary IR Design Studies

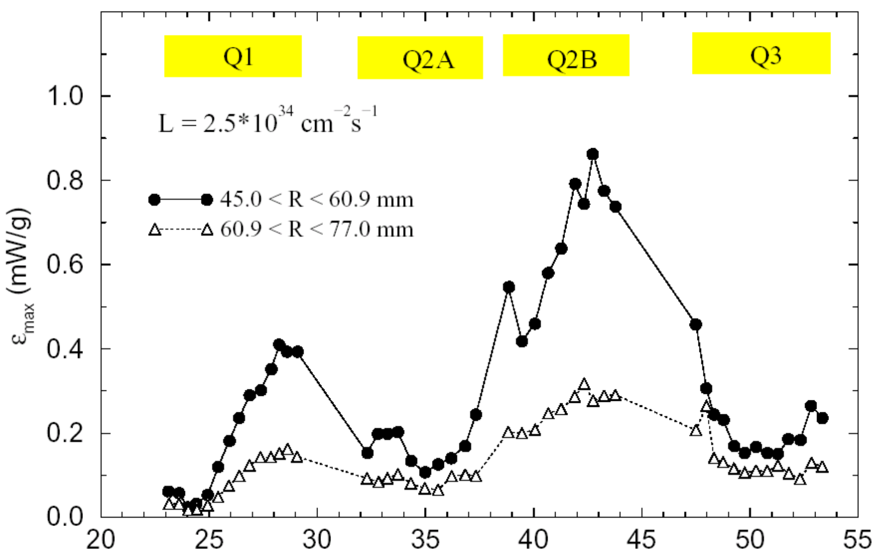
Table 1: IR Parameters

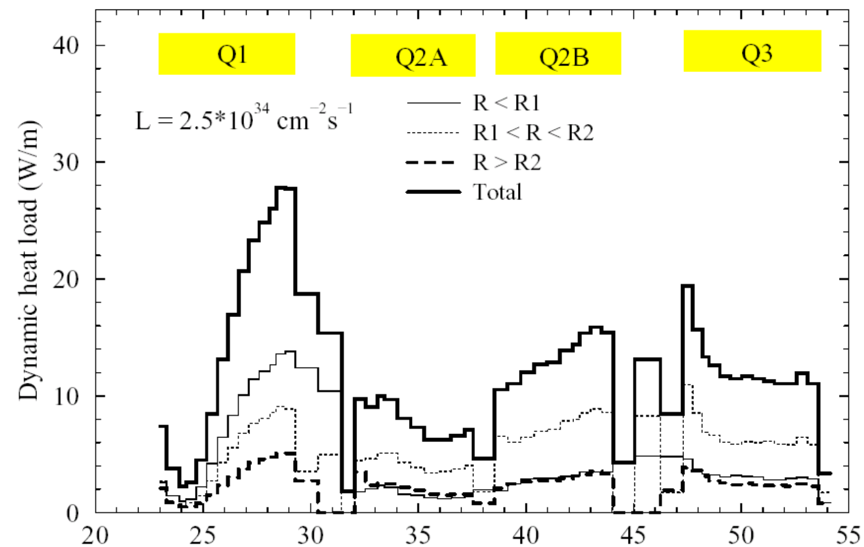
	Base-line	Quad 1st	Dipoles 1st	Quad between	Twin D 1st	Twin Q 1st
IP to Q1 (m)	23	23	52.8	42.5	34	23
D_{quad} (mm)	70	110	100	100	100	100
β^*_{min} (cm)	50	16	26	19	15	10
β_{max} (km)	5	15	23	23	23	23
B_{D1} (T)	2.75	15.3	15	14.6	14.5	14.3
L_{D1} (m)	9.45	1.5	10	12	6	9
D_{D1} (mm)	80	110	135	165	75	105
θ_{cross} (mrad)	0.30	0.53	0.42	0.49	7.5	7.8

Energy Deposition

Energy deposition and radiation are *major* issues for new IRs.

- In quad-first IR, E_{dep} increases both with L and with quad aperture.
  - ε_{max} > 4 mW/g, $(P/L)_{max}$ > 120 W/m, $P_{triplet}$ >1.6 kW for $\mathcal{L} = 10^{35}$ cm^{-2} s^{-1}.
  - Radiation lifetime for G11CR < 6 months at hottest spots.

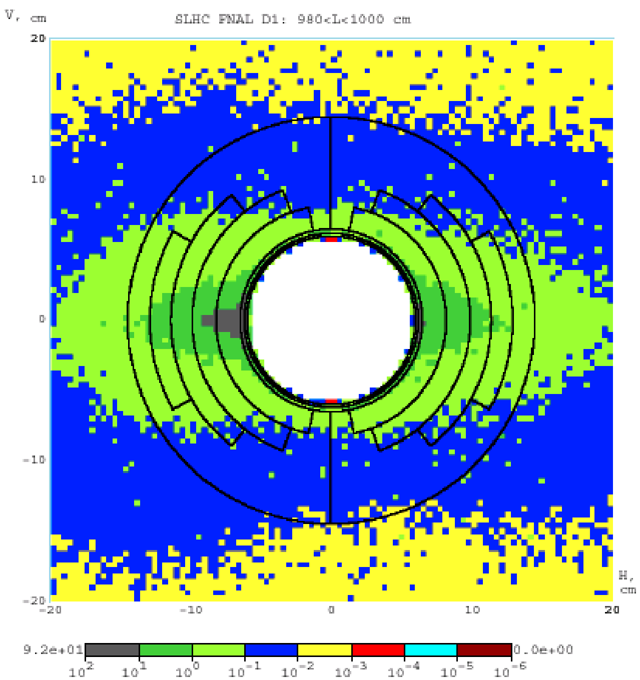


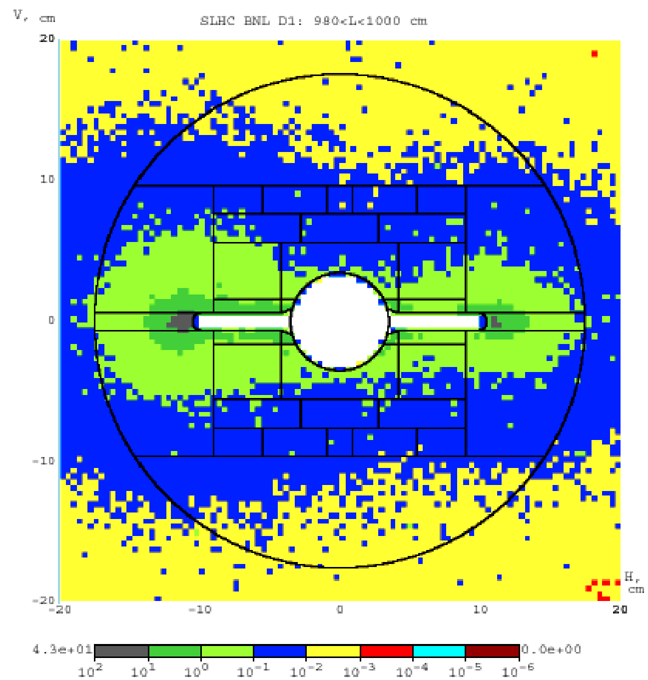


T. Sen, et al., Beam Physics Issues for a Possible 2nd Generation LHC IR, EPAC 2002.

Energy Deposition

- Problem is even more severe for dipole-first IR.
  - ε_{max} on mid-plane ~ 50 mW/g; P_{dipole} ~3.5 kW for $\mathcal{L} = 10^{35}$ cm^{-2} s^{-1}.
  - "Exotic" magnet designs may be required, whose feasibility is not known.





N.V. Mokhov, et al., Energy Dep.Limits in a Separation Dipole in Front of the LHC High-L Inner Triplet, PAC 2003.

Magnet R&D Questions

- What is the maximum D_{quad} for G>200 T/m?
- What is the maximum D_{quad} in a dual-bore quadrupole with 194 mm spacing?
- Can dipoles be made to operate as high as 15 T in the extreme radiation environment at very high luminosity?
- How can the many kW of beam power be removed from the cryogenic magnets for a tolerable cost?
- Are non-parallel axis dual-bore quadrupoles feasible?
- Can good field quality be maintained over the full operating range in very high field, dual-bore dipoles with parallel field directions?
- How can the required very strong correctors (linear and non-linear) correctors be made?

LARP Magnet Program

- Develop Magnet Technology for LHC Luminosity Upgrade
  - Enhance physics opportunities at the LHC
  - Provide tools to AP for optimal IR design
- An ambitious program focusing on Nb_3Sn
  - Large-aperture quadrupoles
    - **Required in all IR upgrade scenarios under consideration**
  - Large-aperture, high-field, beam-separation dipoles
    - **Required in most IR upgrade scenarios under consideration**
- Production-ready IR component designs by 2012

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Program Strategy and Structure

- Extend and quantify limits on key performance parameters
- Issue-driven program designed to develop an enabling technology base for LHC upgrades

Technology Development – LBNL
Quadrupoles – FNAL, LBNL
Dipoles – BNL, LBNL

- 2003 – 05
  - Technology, simple models
- 2006 – 09
  - More complex models (~ 3/yr)
- 2010 – 12
  - Accelerator-ready prototype

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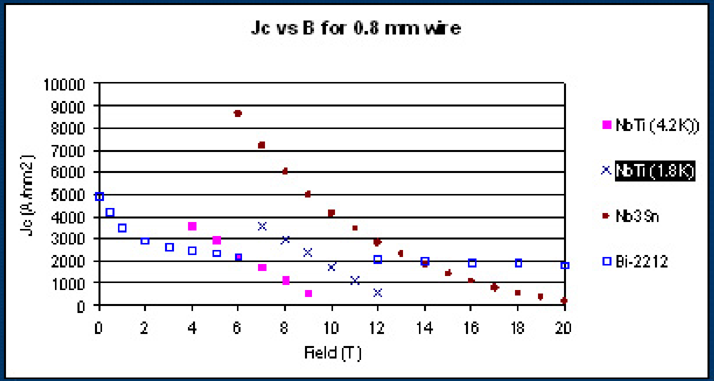
R&D Strategy

- Main Issues
  - High fields and gradients
  - Large beam-induced heat loads
- Extend and quantify limits on key performance parameters
- Issue-driven program designed to develop an enabling technology base for LHC upgrades

Nb_3Sn



- 2003 – 05
  - Technology, simple models
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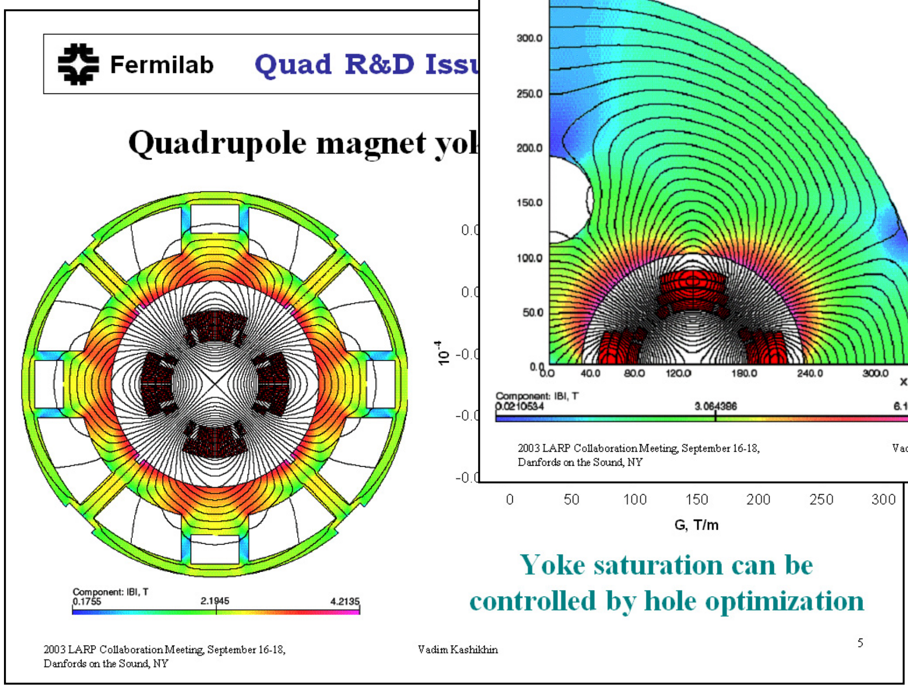
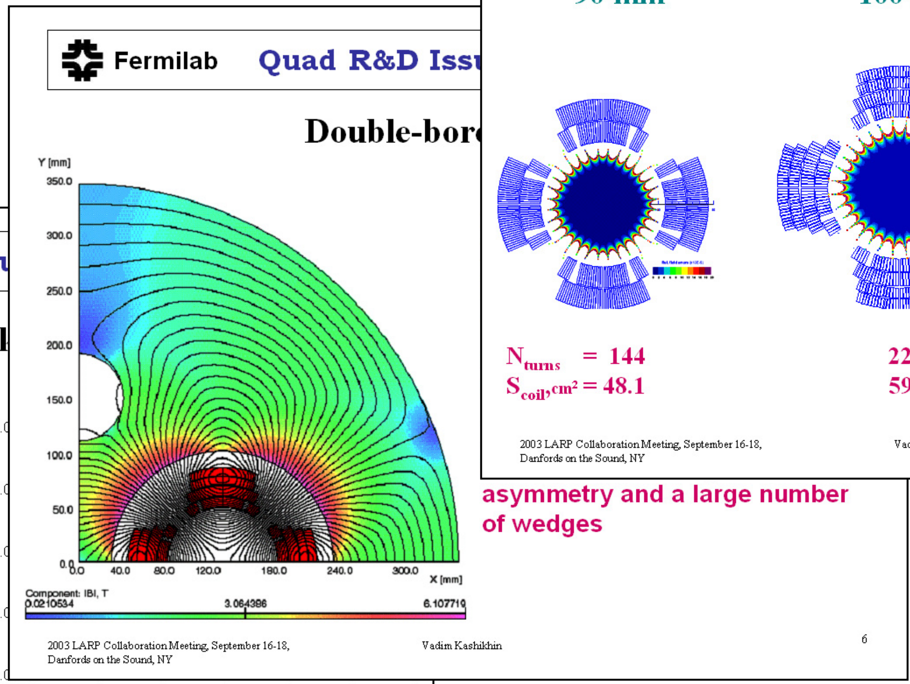
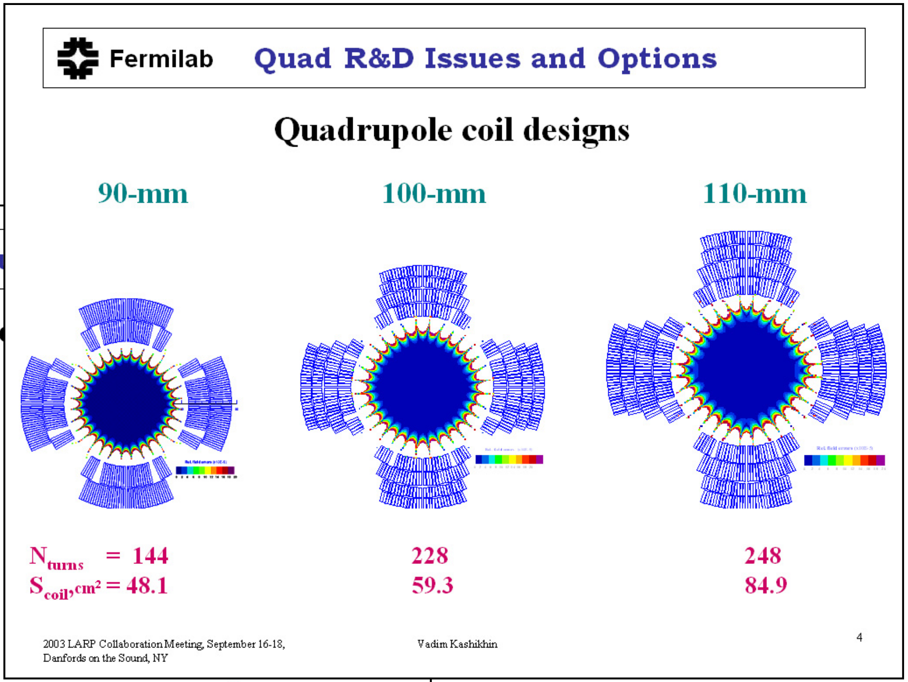
  - Accelerator-ready prototype

IR Upgrade Quadrupole Design Studies

Fermilab is looking at relatively conventional designs.







Max aperture for good field quality?

Coil cooling; cold mass cooling?

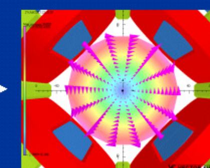
IR Upgrade Quadrupole Design Studies

LBNL is looking at alternate designs and assembly methods.

Racetrack Quads for the LHC IR?

A) for the ultimate LHC IR application

(–) Low magnetic efficiency wrt cos2θ/block
(–) Field quality is more difficult to optimize
... if aperture is measured at the midplane →
... with nested coils (Gupta, ASC-02)
...ensive fabrication



...hnology development

... integrates with the SM program and the bladder/key structure
...ffective method to investigate:
... quality and related mechanical issues
...rials, thermal, quench protection studies

BERKELEY LAB

...6-18, 2003 *Superconducting Magnet Program* Gian Luca Sabbi

Block coil designs.

Technology Development Proposal

- Rapid, cost-effective start using existing techniques and infrastructure
  - Support structure based on LBNL bladder and key assembly technique
  - Use existing D20 tooling for 2-layer coils

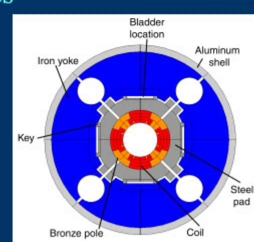
Phase I_a – Mechanical Studies

Phase I_b – 2-layer coil

142 T/m
120 mm bore

Phase I_c – 4-layer coil

230 T/m
90 mm bore



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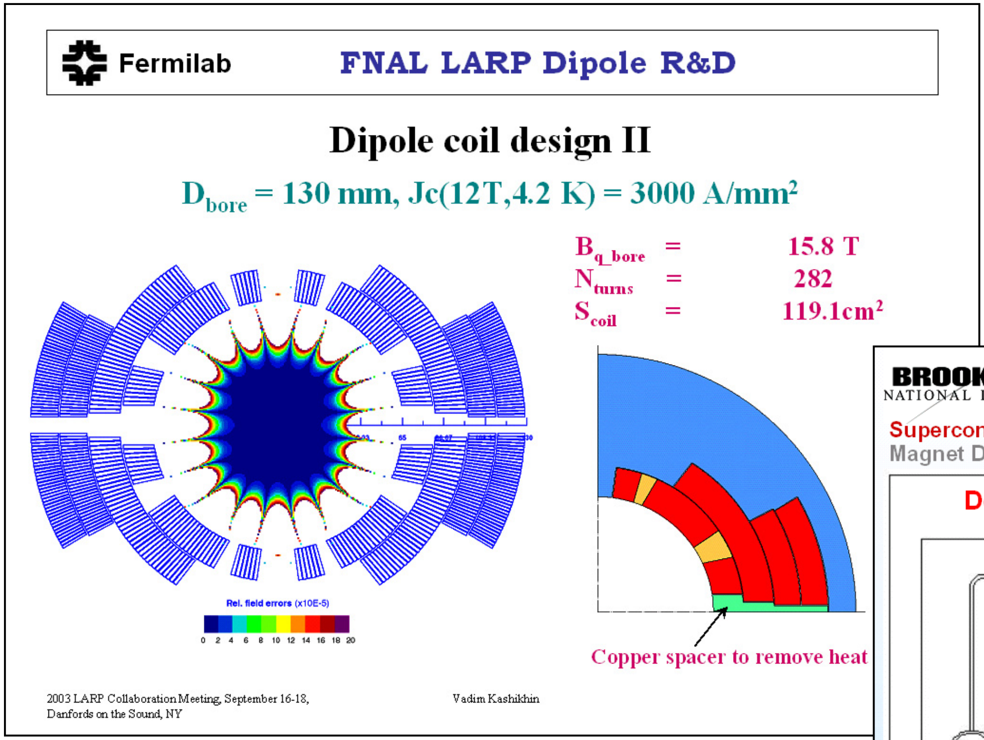
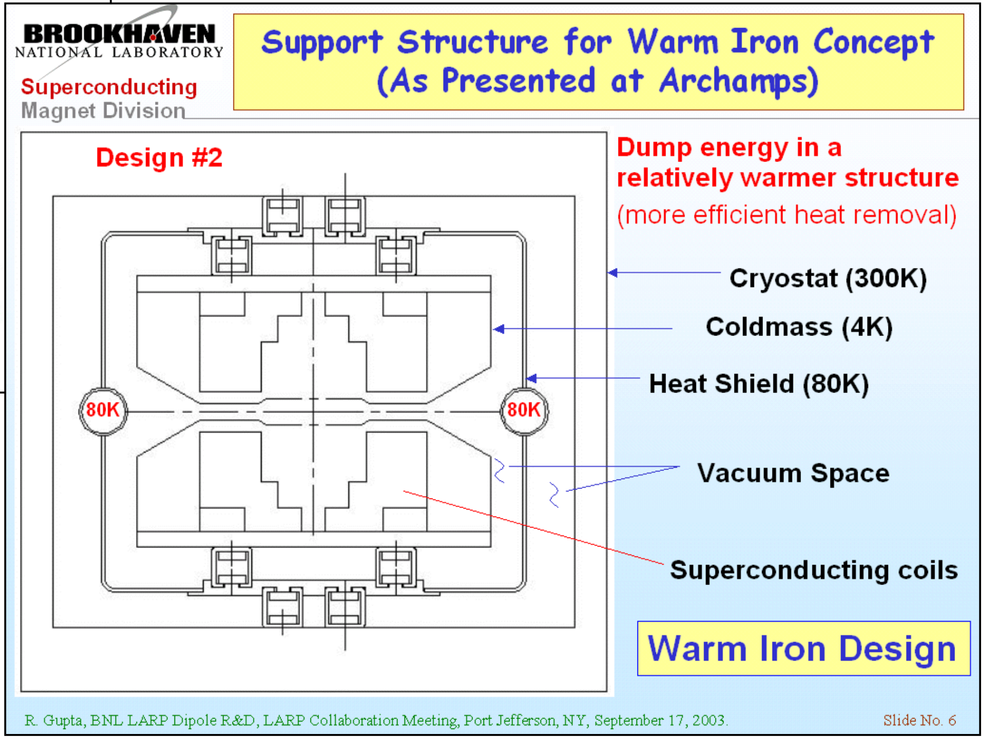
Bladder and key assembly method.

IR Upgrade Dipole Design Studies

Energy deposition on the coil mid-plane (kW's!) is the ***big*** challenge.



Cold-iron, cosθ design
=> cooling?



Warm-iron, open mid-plane design
=> mechanics? field quality?

FY04 Action Items

- Until we prove differently, radiation damage is biggest concern
  - Conservative evaluation
  - Investigate possibility of experiments to measure limits
    - Materials
    - Superconductor
  - FY05 task will be to do tests
  - Need X % of Nikolai
    - User-friendly interface for aperture/magnet studies
- Conceptual studies to maximize effective aperture

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Technology Development is a key early part of the program, especially in the early phases.

FY04 Action Items (cont'd)

- Heat Transfer of composite coils/cold mass
  - Experiments to verify input parameters for models. Big impact on design. Need the details.
  - Can we increase heat transfer of composite coils?
  - What is maximum allowed cryo load? Need a working number
  - Advantages (if any) of 1.8K operation
- Definition of the good field region for the dipoles that is more relevant for the aspect ratio of the beam.
- Build a quad ASAP
- Put together specifications and requirements book.

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FY04 Magnet Program

- Technology Development
  - Racetrack quad
  - Support Structure R&D
    - **Evaluate bladder and key structure**
    - **Labor + most M&S supported by base programs**
  - Heat transfer measurements
- Dipoles
  - Mechanical analysis of BNL design
  - Heat transfer modeling
- Cable R&D
  - Keystoned cable
    - **Map parameter space, new techniques?**
  - Evaluation
    - **Extracted strand measurements**
  - Stress degradation measurements?
- Quads
  - Dual-bore studies
  - Racetrack quad evaluation

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Program Schedule

Fermilab R&D program on LHC IR upgrade quadrupoles

FY2003-2007 - Conceptual Design Studies

FY2006-2010 – model magnet R&D

We start IRQ model R&D in FY06 with simplified 1-m long models (2-layer design) in order to develop basic tooling and infrastructure and start basic technology development.

- **FY2004 – conceptual design of IRQ model**
- **FY2005 – model and tooling design and procurement**

A series of short models will address the issues of magnet quench performance, field quality, mechanics, quench protection, reproducibility, long term performance, etc.

We will start studying length dependent effects with 4-m long coils, as soon as we achieve acceptable quench performance.

FY2010-2012 - Model R&D will be followed by the construction of one or more prototypes containing all of the features required for use in the LHC.

2003 LARP Collaboration Meeting, September 16-18, Danfords on the Sound, NY | Quadrupole Model Magnet R&D | A. Zlobin | 2

Summary

- US LHC Accelerator Research Program has been launched.
- Magnet R&D for a luminosity upgrade will be the single biggest part of the LARP.
  - Fermilab will take the lead on quadrupole R&D.
  - Collaboration among the US labs will be crucial to success.
- The budget does not allow for the construction of model magnets until FY2006.
  - FY2004: mostly design studies.
  - FY2005: technology development experiments.
parts and tooling for FY2006 models.
- Strong coordination with and support from the base Nb3Sn R&D programs will be essential for the success of LARP.